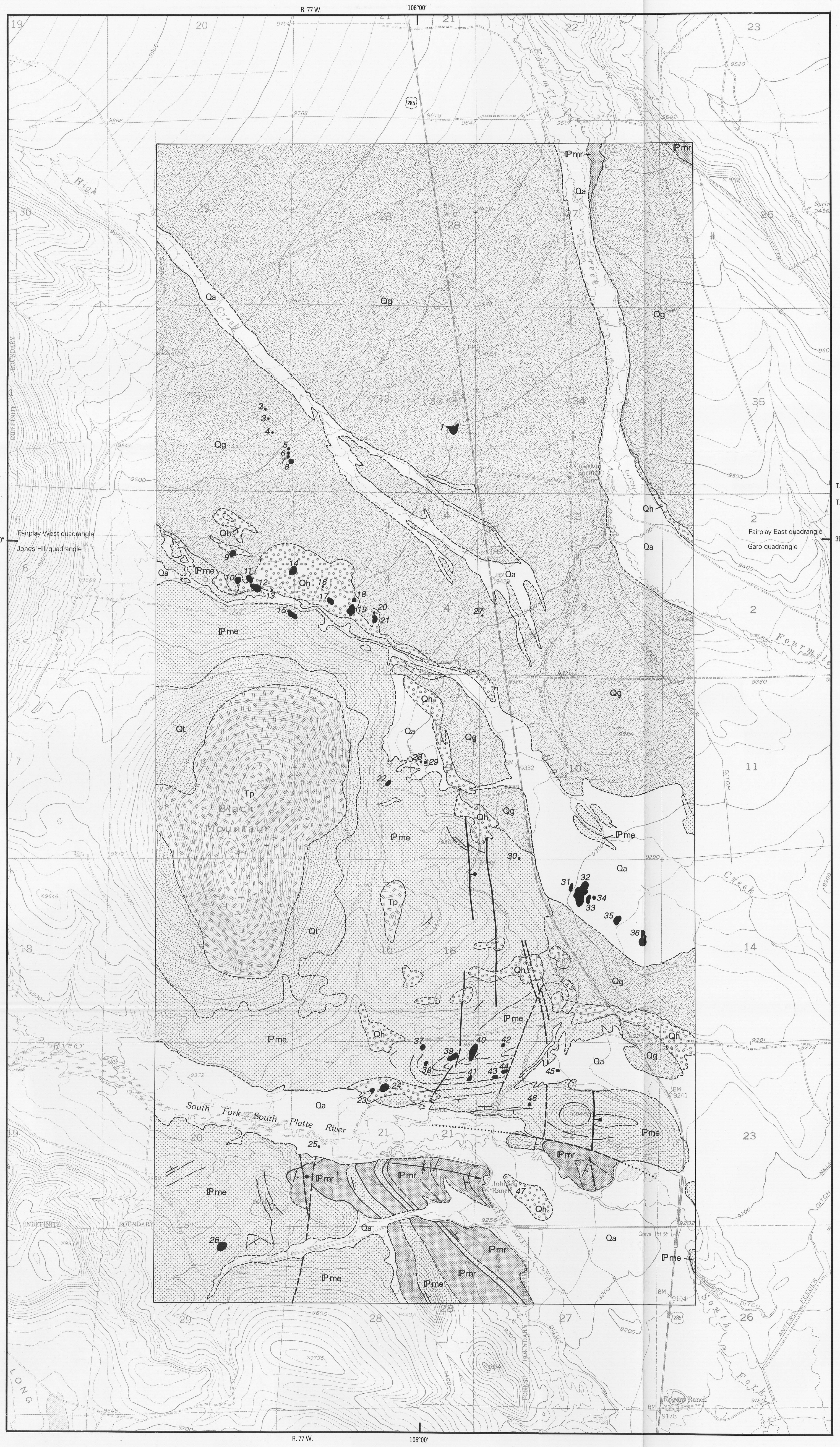

Base from U.S. Geological Survey,
Fairplay East, 1956; Fairplay West, 1960;
Garo, 1956; Jones Hill, 1960.
Polyconic projection. 1927 North American datum

Geology mapped from aerial photographs by
D.R. Shawe in 1994.
Manuscript approved for publication May 3, 1995

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

PHOTOGEOLOGIC MAP SHOWING DISTRIBUTION OF SINKHOLES SOUTH OF FAIRPLAY, PARK COUNTY, COLORADO—A POSSIBLE GEOLOGIC HAZARD

By
D.R. Shawe, T.A. Steven, R.B. Taylor, and C.H. Maxwell
1995

LIST OF MAP UNITS

- Qa — **Alluvium (Holocene)**
- Qt — **Talus and slopewash (Quaternary)**
- Qh — **Hummocky ground (Quaternary)**
- Qg — **Glacial outwash gravel (Pleistocene)**
- Tp — **Porphyritic granodiorite or quartz monzonite (middle Tertiary)**
- **Minturn Formation (Middle Pennsylvanian)**
  - IPmr — **Redbeds facies**
  - IPme — **Evaporite facies**

SYMBOLS

- 22 — **Sinkhole, or coalesced sinkholes (Holocene and Pleistocene)**—Referred to by number in text. Area of Qh labelled No. 47 in SW1/4 sec. 22, T. 11 S., R. 77 W. contains numerous small sinkholes
- **Contact**—Dashed where approximately located or gradational
- **Trace of bedding**—Dotted where overlain by thin surficial materials
- **Fault**—Dashed where approximately located or projected; dotted where concealed. Bar and ball on downthrown side where relative movement known
- **Syncline**—Showing direction of plunge
- **Attitude of bedding**—Dip not measured

INTRODUCTION

A large group of at least 50, and perhaps significantly more, sinkholes partially surrounds Black Mountain 6–10 mi south of Fairplay in South Park, Park County, Colorado. The sinkholes occur in bedrock in the evaporite facies of the Middle Pennsylvanian Minturn Formation, and in Quaternary soil, alluvium, and glacial outwash gravels that overlie the evaporite beds. Sinkholes range in size from small depressions a few feet across to large holes several hundred feet across. Measured sinkholes range in size from about 25 ft in diameter and 2 ft deep to about 235 ft in diameter and 25 ft deep. In places, several sinkholes have coalesced to form depressions as much as 750 ft long and 400 ft wide. One large cluster of small craters is about 1,800 ft long and 600 ft wide. As reported to us by a resident rancher, one small sinkhole collapsed about 10 years ago. The area of sinkholes extends into land now under development for residences, and the sinkholes thus pose a potential hazard that needs to be considered in future development. Also, they might jeopardize existing farmland, structures, and roads (including U.S. Highway 285), as well as projected roads and airstrips.

This report is not a comprehensive evaluation of the distribution and origin of the sinkholes; its intent is to call attention to their presence and to encourage further study. Many but not all of the sinkholes were visited; the geologic map is based mainly on the interpretation of aerial photographs by D.R. Shawe.

GEOLOGIC SETTING

The area in which sinkholes were recognized and mapped is underlain chiefly by evaporite facies of the Middle Pennsylvanian Minturn Formation (DeVoto, 1980), which was intruded by a small stock of Tertiary porphyry. The Minturn Formation in this area is covered widely by Quaternary glacial outwash gravels and locally by Quaternary soil, alluvium, and other surficial materials.

We recognize two facies of the Minturn in the map area. Most extensive is an evaporite facies (IPme) that consists of interlayered beds of gray to white siltstone, shale, and gypsum. Salt layers are present in the subsurface (see, for example, Tweto, 1979; Tweto and others, 1978). The exposed thickness of the evaporite facies in the map area is probably several hundred feet. A second facies (IPmr) consists of redbeds made up of interlayered beds of grayish-red to reddish-brown sandstone, siltstone, and shale, and minor gray limestone; this redbeds facies largely overlies but locally is interbedded with the evaporite facies. The exposed thickness of the redbeds facies in the map area is probably a few hundred feet. Local small thin patches of soil, alluvium, and other surficial materials above the Minturn Formation are not shown on the map.

The Minturn Formation has been folded complexly in places (suggested locally by attitudes and bedding traces shown on map), but we have made no effort to establish a comprehensive map of the folded rocks. Also, several faults that cut the Minturn were recognized on aerial photographs, but again, detailed work on the ground was not undertaken to clarify fault relations.

A small stock of porphyritic granodiorite or quartz monzonite (Tp) of middle Tertiary age (Tweto and others, 1978), about 1.5 mi long and 1.0 mi wide at the surface, intruded the Minturn Formation near the west side of the map area. The stock underlies Black Mountain (figs. 1, 13), and it forms a local prominence on the landscape near the west edge of South Park. A small hill just east of Black Mountain also is underlain by porphyritic granodiorite or quartz monzonite.

Glacial outwash gravels (Qg) of largely Bull Lake age (late Pleistocene), but including some that are older and some younger, cover several square miles in the northern part of the map area (Tweto and others, 1978; Bryant and others, 1981). The maximum aggregate thickness of the gravels is unknown, but it is probably at least 100 ft.

Hummocky ground (Qh) has formed locally near the eroded margins of the glacial outwash gravels and in places on the evaporite facies of the Minturn Formation (IPme). Thin surficial materials of the hummocky ground generally lie on an irregular bedrock surface formed by differential removal of soluble minerals in the evaporite facies.

An apron of talus (Qt) that merges downslope into slopewash deposits surrounds the Black Mountain stock. The upper contact of the apron is well defined at the line of abrupt steepening of the hillslope, which is attributed to resistance of the intrusive rock to erosion. The lower contact of the apron is indefinite where it wedges out against the underlying evaporite facies of the Minturn (IPme).

Stream-deposited alluvium (Holocene; Qa) occupies the valleys of the South Fork of the South Platte River, Fourmile Creek, High Creek, and some lesser drainages.

SINKHOLES

Sinkholes are present in a variety of geologic materials throughout the map area. They are particularly abundant where relatively thin surficial materials overlie evaporite facies of the Minturn Formation; also, they commonly occur where evaporite-facies rocks are exposed at the surface. For convenient reference, the sinkholes and clusters of sinkholes are numbered on the map (Nos. 1–47; the numbering is by 7 1/2-minute quadrangle: 1–8 in Fairplay West; 9–26 in Jones Hill; and 27–47 in Garo).

Sinkholes are described in the following paragraphs according to the geologic setting in which they formed: bedrock (evaporite facies of the Minturn Formation, IPme), glacial outwash (Qg), hummocky ground (Qh), and alluvium (Qa).

A large cluster of sinkholes (Nos. 37–46) developed in the evaporite facies north of Johnson Ranch on the north side of the valley of the South Fork of the South Platte River. These sinkholes were mapped on aerial photographs and were not visited on the ground. A shallow, poorly defined sinkhole (No. 26) in the evaporite facies in the southwest corner of the map was observed on the ground. Thin surficial soil (not mapped) covers much of the bedrock here, and the sinkhole itself is characterized by greater development of soil and denser vegetation (grass and small brush). Several apparently active coalescing sinkholes in the evaporite facies (No. 15) occur in a grove of aspen trees a few hundred yards north of Black Mountain. One of these is drained by a small subvertical cavern of unknown depth (fig. 2).

A small sinkhole (No. 13; fig. 3), about 300 yds to the northwest from the sinkholes at site No. 15, formed suddenly about 10 years ago, according to a resident rancher. The sinkhole, the bottom of which is in clayey material of the evaporite facies, lies at the edge of hummocky ground that here borders glacial outwash gravels. The sinkhole is 29 ft in diameter and is 7 ft deep, and it has raw, unvegetated walls. The depth is unusually great for a sinkhole of this diameter, and it probably reflects the very young age of the sinkhole; in older sinkholes, slumping of rim materials has subdued their appearance by enlarging their diameters and decreasing their depths.

An aligned group of sinkholes (Nos. 2–8; see also fig. 1) in glacial outwash gravel in the northwestern part of the map area appears to have formed above a north-trending fissure. The occurrence of several north-trending faults in bedrock in the southern part of the map area suggests the likelihood of such faults farther north beneath the glacial gravels. Several of the sinkholes (Nos. 5–8) occupy a slight depression in the surface of the outwash gravel, suggesting a broader subsurface solution of the evaporite facies than indicated by just the sinkholes alone.

The largest sinkhole (No. 1; fig. 4) observed in the vicinity of Black Mountain lies in glacial outwash gravel just west of U.S. Highway 285 in the north-central part of the map area. The sinkhole, visible from the highway, is about 235 ft in diameter and 25 ft deep. Two prominent gullies enter the sinkhole from its northwest and northeast edges, showing that significant surface water has drained into the structure. Eyewitness evidence indicates that water draining into the sinkhole percolates rapidly into the subsurface. One of us (C.H. Maxwell) observed the sinkhole during a drenching rainstorm: rivulets of rainwater entered the crater and disappeared rapidly into the ground in the bottom of the structure.

In the general area of sinkhole No. 13, a large number of sinkholes (Nos. 9–12, 14, and 16–21) formed within hummocky ground near the margin of glacial outwash gravels that lie to the north. Several coalescing sinkholes (No. 14) are depicted in a stereoview (fig. 5). Among this group of sinkholes, a few very small ones are sharply defined and probably formed more recently than the others; the larger sinkholes contain untilted large bristlecone pines and are of significant age. The group of coalescing sinkholes suggests a continuum of development through perhaps a rather long time interval. One isolated sinkhole (No. 18) contains a large bristlecone pine that leans obliquely inward from its position just below the rim of the sinkhole (fig. 6). Inward tilt of the pine perhaps resulted from collapse of the sinkhole that followed earlier growth of the pine. Sinkhole No. 17 shows evidence of relatively recent collapse. Several dead bristlecone pines lie within the structure, possibly killed by disruption of roots at the time of collapse, and the sinkhole walls are relatively steep (fig. 7).

A large patch of hummocky ground just east of the Johnson Ranch contains numerous small sinkholes (No. 47), attesting to recent solution of evaporite facies near the surface.

The presence of a number of sinkholes in Holocene alluvium attests to their relatively young age. A cluster of sinkholes (Nos. 31–36) was mapped in alluvium just east of U.S. Highway 285 in the east-central part of the map area. Small patches of evaporite facies rocks are exposed locally, indicating that bedrock is near the surface here. The sinkholes are broad and shallow (fig. 8), suggesting that they may have been filled rapidly by alluvium as the sinkholes developed in the underlying rock. Groups of coalesced sinkholes (Nos. 32 and 36; fig. 9) clearly show the scalloped outlines of individual sinkholes that form the groups. Several small potholes (a few feet in diameter and a foot or so deep; figs. 10, 11) were observed in marshy ground near the coalesced sinkholes. At the time we observed them (September 1992), potholes were both water filled (fig. 10) and dry (fig. 11); rounded stream pebbles and cobbles line the bottoms of the potholes. No sand-size nor smaller particles are present among the pebbles and cobbles, suggesting that upwelling water has flushed through the alluvium to remove the fines. The cluster of sinkholes in alluvium thus marks a zone of at least seasonal discharge of the hydrologic system associated with the sinkhole cluster.

A small sinkhole (No. 25; figs. 12, 13) formed in Holocene alluvium on the south bank of the South Fork of the South Platte River about 1 mi west of Johnson Ranch. It is remarkably circular and filled with water. The sinkhole lies on the projection of a north-trending fault that offsets beds in the Minturn Formation just to the south. Solution of evaporite minerals probably was localized in the subsurface along the fault, eventually leading to the formation of the sinkhole in the alluvium. Abundant gypsum float covers the surface above evaporite-facies rocks immediately south of the sinkhole.

Several broad, shallow sinkholes occur in alluvium along the courses of Fourmile Creek and High Creek east of the map area.

CONCLUSIONS

A large number of sinkholes having a wide range of sizes and relative ages have formed in the vicinity of Black Mountain in South Park a few miles south of Fairplay. The sinkholes formed in the evaporite facies of the Minturn Formation and in thin surficial materials that in places cover the evaporite-facies rocks. The sinkholes have been developing intermittently, probably throughout the Pleistocene and Holocene, and some are still active. Some sinkholes are in or near areas of recent housing developments along the South Fork of the South Platte River and northwest of Black Mountain, and they thus may pose a threat to the safety of the developments. Further detailed study of this area is strongly recommended.

ACKNOWLEDGMENT

Valuable reviews of the map and text were provided by Alan Wallace and Richard Van Loenen.

EPILOGUE

We were first attracted to an investigation of the sinkholes in South Park in the belief that they might have formed by impact of a cluster of meteorites. Our initial interpretation was reinforced when we became aware of an obscure early report (Opik, 1964, *cited in* Freeberg, 1966) that described circular depressions near Fairplay, Colorado, as suspected meteor craters. However, the report of a South Park rancher (Dave Neukirch, oral commun., June 1991) regarding recent collapse of sinkholes, as well as the details described herein, convinced us of the sinkhole origin of the depressions. We might add that, on a topographic map of the Fairplay East 7 1/2-minute quadrangle used as a field worksheet by the late Ogden Tweto in the 1960's and 1970's, our sinkhole No. 1 is labeled as a sinkhole.

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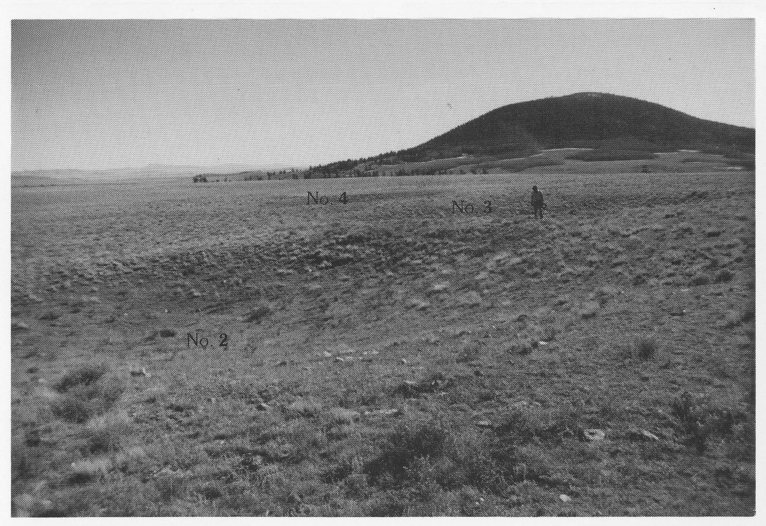


Figure 1. View south to Black Mountain across crudely aligned sinkholes (Nos. 2, 3, and 4) in glacial outwash gravel (Qs). The near sinkhole (No. 2) is 93 ft in diameter (measured in a N. 53° W. direction) and 6 ft deep.

Figure 2. Solution-collapse cavern at the bottom of an active sinkhole among a group of coalescing sinkholes (No. 15) north of Black Mountain. Aspen tree at the edge of the cavern is about 12–14 in. in diameter.

Figure 3. Recently collapsed sinkhole (No. 13) on the north side of High Creek north of Black Mountain. The sinkhole is 29 ft in diameter and 7 ft deep.

Figure 4. View east across large sinkhole (No. 1) near U.S. Highway 285, visible a few hundred feet beyond the sinkhole. The sinkhole is 235 ft in diameter (measured in a N. 13° W. direction; diameter measured to avoid areas of enlargement caused by gullies that enter the sinkhole) and 25 ft deep. Note the prominent gullies entering the sinkhole from the northeast and northwest sides (at the left of the structure). The sinkhole formed in glacial outwash gravels (Qg).

STEREOPAIR

Figure 5. Stereoview north to a cluster of sinkholes (No. 14) in hummocky ground (Qh) at the margin of glacial outwash gravels (Qg) north of Black Mountain.

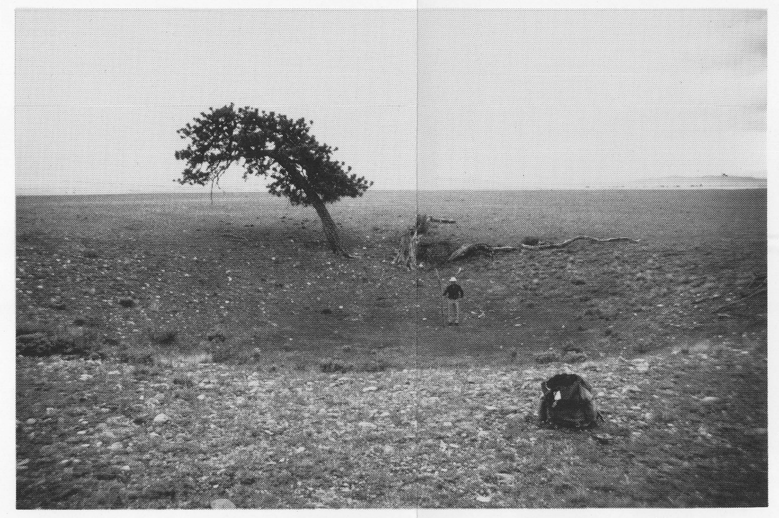


Figure 6. Isolated sinkhole (No. 18) north of Black Mountain containing a tilted bristle-cone pine. Inward tilt of the pine suggests a late episode of collapse following earlier growth of the pine within the sinkhole.

Figure 7. Relatively young sinkhole (No. 17) showing generally unvegetated steep walls and containing several dead bristlecone pines.

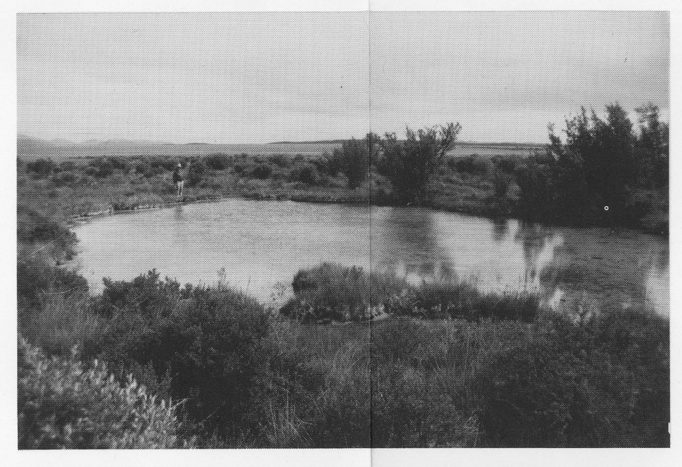


Figure 8. Broad, shallow sinkhole (No. 34) in alluvium (Qa) along High Creek east of U.S. Highway 285; view to northeast.

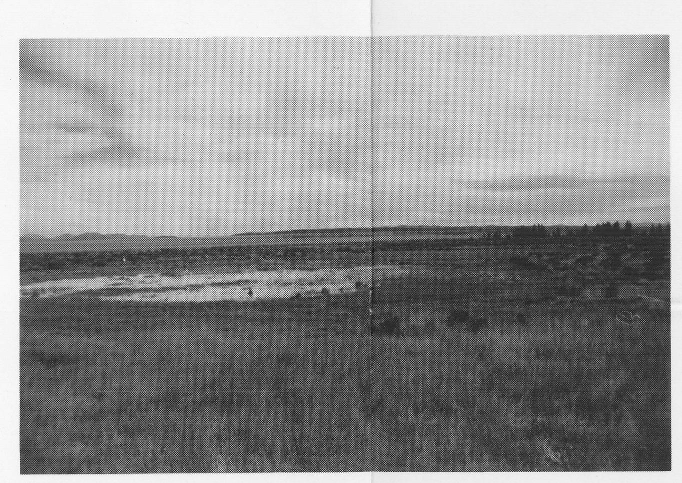


Figure 9. Broad, shallow coalesced sinkholes (No. 36) in alluvium (Qa) along High Creek east of U.S. Highway 285; view to northeast. Note scalloped margin near right edge of the photograph due to intersecting rims of separate eccentric sinkholes.

Figure 10. Small water-filled pothole in marshy ground near coalesced sinkholes (No. 32) along High Creek east of U.S. Highway 285. Note lack of fines among pebbles and cobbles that line the bottom of the pothole.

Figure 11. Small dry pothole near the pothole shown in figure 10, also lined with pebbles and cobbles.

Figure 12. Relatively young water-filled sinkhole (No. 25), about 30 ft in diameter, on the floodplain of the South Fork of the South Platte River about 1 mi west of Johnson Ranch; view to northeast. Note older, dry sinkhole to the right of the water-filled structure.

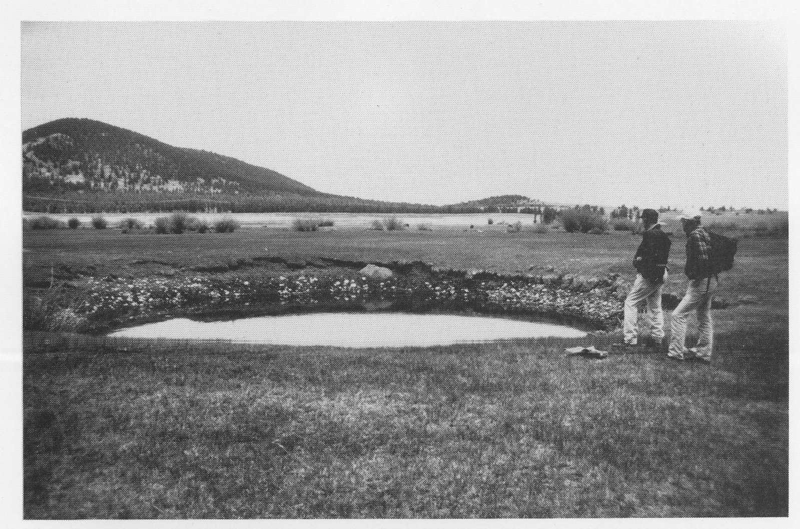
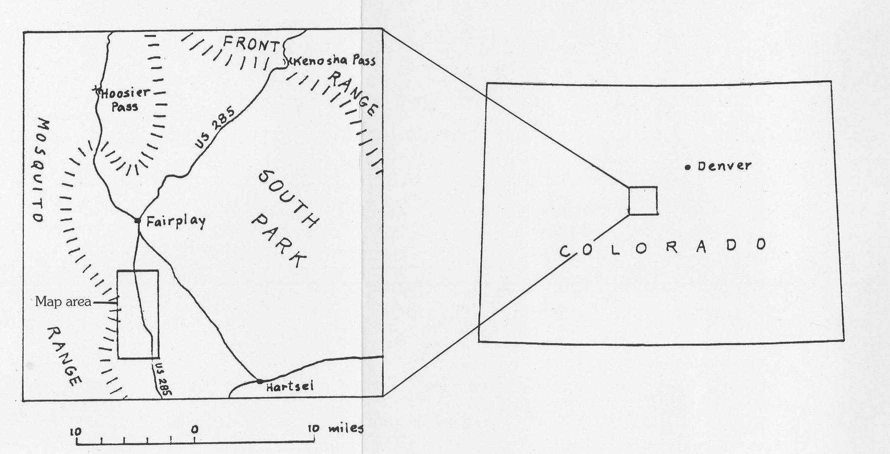


Figure 13. Close view of sinkhole No. 25; note slumped walls that expose flood-plain alluvium. View to the north; Black Mountain in the distance at the left. Black Mountain and small hill to its right are underlain by porphyritic granodiorite or quartz monzonite (Tp) of middle Tertiary age.



INDEX MAP

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1995

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